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Filter Plant Design for Asbestos Fiber Removal

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Water filtration plants used to remove asbestos fibers should be designed to produce filtered water with very low turbidity (0.10 ntu or lower). Flexibility in plant operation, especially with respect to conditioning raw water for filtration, is a key design factor. Preconditioning and filtration should be interdependent portions of the calarification process. Water quality monitoring is very important; careful control of Ph is needed during coagualation; filtered water turbidity should be monitored continuously so filters can be backwashed before large amounts of floc and asbestos fibers are discharged from the filter into the treated water. Design data and treatment results are also presented.

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JOURNAL ARTICLE

FILTER PLANT DESIGN FOR ASBESTOS FIBER REMOVAL

By Gary S. Logsdon,[1] Glenn L. Evavold,[2] Members, ASCE, James L. Patton,[3] and Jack Watkins, Jr.[4]

ABSTRACT: Water filtration plants used to remove asbestos fibers should be designed to produce filtered water with very low turbidity (0.10 ntu or lower). A key design factor in accomplishing this is to provide for flexibility in plant operation, especially with respect to conditioning raw water for filtration. The preconditioning and the filtration should be viewed as interdependent portions of the clarification process, which should be designed to operate at maximum efficiency. Water quality monitoring is very important. Adequate monitoring capability must be provided. Careful control of pH is necessary during coagulation, and filtered water turbidity should be monitored continuously so filters can be backwashed before large amounts of floc and asbestos fibers are discharged from the filter into the treated water. Pilot plant studies as well as design and operation of full scale plants show that producing low turbidity water is attainable for Lake Superior and Cascade Mountain waters. Design data and treatment results are also presented.

INTRODUCTION

Asbestos minerals have a long history of beneficial uses, but the questions about health hazards that have been raised in recent years have resulted in studies related to the health effects of ingested asbestos and to techniques to reduce the concentration of asbestos fibers in drinking water. After amphibole asbestos was found in Lake Superior and in the unfiltered drinking water of Duluth and other north shore communities in 1973, these communities adopted a policy of reducing the concentration of asbestos in their water. Since 1973, considerable effort has been made to learn to what extent asbestos fibers are found in water and how well the fibers are removed by the filtration process (2,8,11).

This paper will focus on the design of four filtration plants intended to remove asbestos fibers. Designs are presented first as schematic diagrams and then in a process-by-process fashion so that various concepts can be compared.

TREATMENT PLANTS REVIEWED

Treatment plants analyzed in this paper are located along the north shore of Lake Superior and at Everett, Washington. The latter is included because of the extensive pilot plant studies of filtration of Cas-

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cade Mountain waters that were made prior to the Everett design. Construction on this plant was completed in July, 1983.

Lake Superior Plants.—Lake Superior water quality generally has been excellent. From 1952–1972, raw water turbidity at the intake to Duluth's pumping station was equal to or less than 1 ntu, 90% of the time (1). Since 1971, data have shown that raw water turbidity has been equal to or less than 1 ntu about 70% of the time (the difference in frequency being explained by purchase of a modern turbidimeter in 1971 by the utility). Raw water turbidity at Duluth usually exceeds 10 ntu only once or twice per year, when violent storms on Lake Superior stir up bottom sediments near the shore in the Duluth area. Before the treatment plant was built in Duluth, two to three days' of storage capacity was utilized in the distribution system to avoid pumping high turbidity water into the system. Because of the excellent quality of the lake, neither Duluth nor Two Harbors had a filtration plant in 1973.

The filtration plants now in use at Duluth and Two Harbors were designed and are operated to remove amphibole fibers. The existing Silver Bay filtration plant was modified and upgraded to meet the more stringent performance goals of plants that are operated for asbestos fiber removal. Plant designs were based on pilot plant research done in 1974 in an effort funded jointly by the Environmental Protection Agency (EPA) and the U.S. Army Corps of Engineers (4). A review of asbestos fiber data and treatment results was published (9), as was a summary of the pilot plant study, along with the proposed Duluth plant design (14). Later Patton published a detailed paper describing the design of the Duluth filtration plant (12).

Cascade Mountains.—Extensive pilot plant filtration studies conducted at Everett were described by Watkins, Ryder, and Persich (15). In 1977, 53 pilot plant test runs were made. A 6.1 L/min pilot plant was used to evaluate three processes: (1) Conventional treatment; (2) direct filtration (with flocculation but not sedimentation); and (3) in-line filtration (neither flocculation nor sedimentation).

The Seattle Water Department conducted pilot plant studies from January, 1977–August, 1978 on the Tolt watershed. In excess of 170 filter runs were made with a 76 L/min package plant. In this study, funded by the EPA, almost 150 asbestos analyses were performed. This work has been described by Kirmeyer (5,6).

Data from both the Everett study and the Seattle research were available when the Everett Concept Report and Initial Layout (7) was prepared. Therefore, conclusions could be drawn about the processes needed at Everett to condition and filter the water and about the water quality (turbidity) goal that would be associated with effective asbestos fiber removal.

Cascade Mountain waters at Seattle and Everett are very high quality waters, equal to Lake Superior in clarity, and quite low in dissolved solids. Buffering capacity is very poor. At Everett, turbidity of Lake Chapelain averages less than 1 ntu. This could increase in the future because of a proposed construction project. Raw water quality, however, is expected to remain relatively high, with maximum turbidity increasing to about 15 ntu (7). The Everett plant, like those on Lake Superior, has been designed to treat clear raw water.

Design of Plants

Design data for the various plants are summarized in Table 1. This table includes information on waste handling, in addition to a summary of the water treatment processes employed for clarification and data on typical chemical dosages being used. Schematic diagrams of the plants are shown in accompanying figures.

Processes utilized at the plants include variations of direct filtration as well as conventional treatment. The plant at Duluth can be operated with rapid mixing, rapid mixing and flocculation or rapid mixing, flocculation, and sedimentation ahead of the filters (Fig. 1). Two Harbors and Silver Bay (both shown in Fig. 2) utilize rapid mixing, flocculation, and filtration. Treatment facilities for rapid mixing, flocculation, and filtration have been built at Everett (Fig. 3).

Analysis of Unit Processes

Preparing Water for Filtration.—All of the plants are designed to permit the use of coagulant (alum) and polymer to condition the water for filtration. Chemicals can be added both in the rapid mixing step and prior to filtration. Flexibility in chemical addition lets the plant operator cope with raw water quality changes, and is a desired plant feature. Treatment variations are also possible with rapid mix. Two or three back mix units in series are used in each plant. This allows mixing time and energy to be varied.

TABLE 1.—Treatment Plant Data

Design data (1)	Duluth Lakewood Plant (2)	Two Harbors (3)	Silver Bay (4)	Everett (5)
		(*a*) Hydraulics		
Design flow, mgd (million liters/day)	30 (114)	2.6 (9.8)	2.3 (8.7)	50 (190)
Maximum capacity, mgd (million liters/day)	36 (136)	3.2[a] (12) 2.6[b] (9.8)	4.4 (17)	100 (378)
Typical flow when data collected, mgd (million liters/day)	20 (976)	2.0 (7.6)	1.2 (4.5)	Data not available yet
		(*b*) Chemical Application		
At rapid mix	9 mg/L alum 0.07 mg/L 985N caustic soda	12 mg/L alum 0.14 mg/L 985N	13 mg/L alum 0.10 mg/L 985N	Operating data not available at time of publication
Before filter	0.006 mg/L 985N	—	—	
pH to filter	6.9 summer 7.35 winter	6.9	7.15	
		(*c*) Rapid Mix		
Type	Turbine	Axial flow prop	Axial flow prop	Axial flow prop
Number	3 in series	2 parallel sets of 2 in series	2 parallel sets of 2 in series	2 in series
Mix time at design flow (theoretical detention time)	30 sec each	8.5 min total	8.1 min total	20 sec
Intensity, G, sec^{-1}	500	About 200	About 220	200

TABLE 1.—*Continued*

(1)	(2)	(3)	(4)	(5)
		(*d*) Flocculation		
Type	Horizontal paddle	Radial flow turbine	Axial flow prop	Horizontal paddle
Number in series	4	2 parallel sets of 2	2 parallel sets of 2	3
Intensity, *G*, sec^{-1}	About 4–45	About 20	About 20	70–20
Floc time at design flow (theoretical detention time)	40 min total	38.5 min total	40.5 min total	30 min total
		(*e*) Sedimentation		
Type of basin	Rectangular, horizontal flow	None	None	None
Theoretical determination time	140 min			
		(*f*) Filtration		
Rate at design flow, gpm/sf (meters/hr)	4.9 (12)	4.0 (10)	2.6 (6.3)	4 (10)
Typical operating rate, gpm/sf (meters/hr)	3.3 (8.1)	3.1 (7.6)	3.0 (7.3) (one filter operating)	
Typical run, hours direct filtration	22	15	7	Pilot plant indicated 18 hour runs with 1 ntu raw water
Conventional	32	—	—	
		(*g*) Backwash		
Rate, gpm/sf (meters/hr)	16.3 (40)	13.3 (32)	5.5 (13) (low rate to avoid media loss)	26.5 (65)
Duration, min	6	15	10	
Surface wash rate, gpm/sf (meters/hr)	2.6 (6.3)	0.67 (1.6)	0.84 (2.0)	Up to 20 0.71 (1.6) recommended
Duration	Until backwash = 13 gpm/sf (32 m/hr)	7 min	4 min	—
Polymer used	None	None	None	Design permits use
		(*h*) Waste Handling		
Discharge time	Intermittent	Intermittent twice per week estimate. 1,350 gpd	Intermittent once per day estimate 550 gpd	Intermittent
Holding basin volume, gallon (m^3)	240,000 (908)	20,400 (77)	29,700 (112)	
Thickening time	4.8 hr	2.7 hr	4.0 hr	
Treatment	Upflow flocculator clarifier to thicken wash water, overflow to head of plant, underflow to lagoon for natural freezing	Wash water treated in upflow clarifier, overflow recycled to plant, underflow to municipal sewer	Wash water treated in upflow clarifier, overflow recycled to plant, underflow stored and trucked to wastewater plant	Wash water held in storage ponds, supernatent recycled to plant, sludge trucked to land application site
Ultimate disposal of solids	Landfilled after freezing, thawing and dewatering	Processed with wastewater sludge	Processed with wastewater sludge	Land application

[a]Based on 5.6 gpm/sf.
[b]Limit of present pumping capacity.

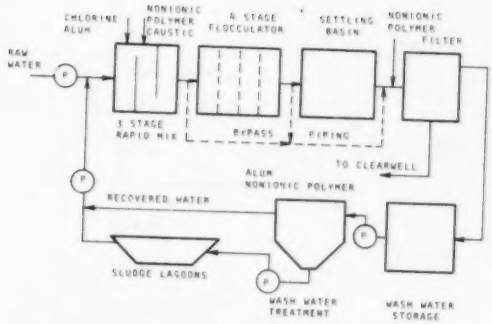

FIG. 1.—Flow Diagram for Filtration Plant at Duluth, Showing Treatment Train Options

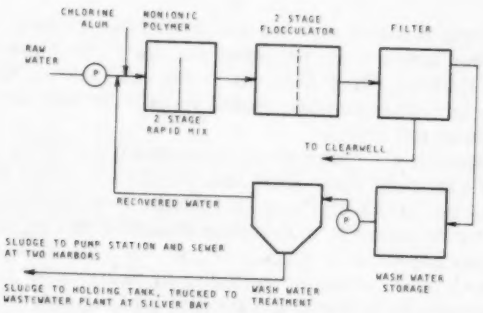

FIG. 2.—Flow Diagram for Filtration Plants at Two Harbors and Silver Bay

Flocculation is (or can be) employed at all plants, with the number of stages varying from two to four. Horizontal paddles, radial flow turbines, and axial flow propellors are used to provide the slow stirring needed to develop the floc for subsequent treatment. Flocculation times range from 30 min–40 min. Tapered flocculation is used at Everett.

Use of sedimentation is optional at Duluth. A basin formerly used as a chlorine contact chamber was converted during the plant construction so that it can now serve as a flocculation basin and sedimentation basin. Both processes or sedimentation alone can be bypassed at Duluth when water quality permits.

Filtration.—Dual or mixed media filters with 30 in.–36 in. (0.76 m–0.91 m) of media are used at each plant (Table 2). At Duluth three mixed media filters and one dual media filter were installed to compare the two media concepts.

The release of air in filter media during filter runs causes air binding and related operating problems such as shorter runs and turbidity breakthrough. Air release in the media can be greatly reduced or prevented by providing a sufficient depth of water over the top of the filter media so that a positive head is provided under all operating conditions. At

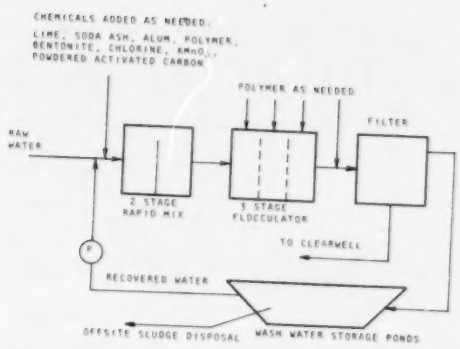

FIG. 3.—Flow Diagram for Everett Filtration Plant

Duluth the depth of water over the top of the filter media is about seven feet. Deep filter boxes were provided for the Everett plant and were used at Two Harbors. Deep filter boxes are not used at Silver Bay because the major reconstruction needed to provide this design concept would have been too costly.

Process Monitoring.—Monitoring of treatment processes is an important aspect of successful filter operation, particularly when filters are operated for asbestos removal. Plants at Duluth, Two Harbors, Silver Bay, and Everett are designed to employ continuous turbidity monitoring at each filter. This approach is much more sensitive to changes in filtered water quality than is measuring turbidity in clearwell effluent, because clearwell water quality indicates the average quality produced in the plant rather than the quality from a single filter. Monitoring at individual filters gives plant operators the capability to backwash filters before tur-

TABLE 2.—Filter Media Data

Location of filters (1)	Filter material listed top to bottom (2)	Depth, in inches (centimeters) (3)	Effective size, in millimeters (4)	Uniformity coefficient (5)
Duluth dual media filter one installed	Anthracite	21 (53)	1.0–1.1	1.7
	Sand	9 (23)	0.42–0.45	1.35–1.7
Duluth mixed media filters three installed	Anthracite	16.5 (42)	1.0–1.1	1.7
	Sand	9 (23)	0.42–0.45	1.35–1.7
	Garnet	4.5 (11)	0.21–0.32	1.8
Two Harbors	Anthracite	16.5 (42)	1.0–1.1	1.7
	Sand	9 (23)	0.42–0.55	1.8
	Illmenite	4.5 (11)	0.18–0.32	1.8
Silver Bay	Anthracite	15 (38)	1.16	1.43
	Sand	15 (38)	0.45	1.41
Everett	Anthracite	22 (56)	0.96	1.82
	Sand	11 (28)	0.45	1.56
	Garnet	3 (7.6)	0.34	1.53

bidity rises sharply and fibers are discharged because of a turbidity breakthrough.

Waste Disposal.—Treatment plant waste disposal practices vary considerably. Wash water and sludge at Duluth are stored in sludge lagoons and frozen naturally in the winter. After the spring thaw, supernatant is returned through the wash water treatment system to the head of the plant (before the rapid mix) and the dewatered solids remain in the lagoon. When enough solids accumulate, they will be removed and buried in a land fill. Sludges at Two Harbors and Silver Bay are thickened and added to municipal wastewater sludge. Wash water at Everett is discharged to sludge storage ponds. After the solids concentrate to about 6%, the sludge will be applied to land. Supernatant is returned to the plant.

Operating Results

Data from pilot plants and treatment plants have shown that the concentration of asbestos fibers in water can be substantially reduced by filtration (5,6,8,15).

Lake Superior Plants.—The Lakewood filtration plant at Duluth, in operation since the beginning of 1977, has been operated specifically for asbestos removal longer than any other plant; therefore, more data have been accumulated here. Duluth monitoring data are shown in Fig. 4. Typically, filtered water has a turbidity of 0.05 ntu or lower, and amphibole fiber counts are below 0.10×10^6 fibers per liter (f/L). Filtered water quality is not influenced greatly by short term increases in raw water turbidity or amphibole fiber concentration. In the fall of 1977, two severe storms on Lake Superior raised turbidity above 10 ntu, and raw water amphibole fiber counts climbed to $1{,}200 \times 10^6$ f/L and 830×10^6 f/L. Filtered water counts, however, remained low: 0.048×10^6 f/L and 0.029×10^6 f/L, respectively.

At Duluth samples of clarified wash water and lagoon supernatant were analyzed for asbestos because these liquid streams were recycled through the plant. One lagoon decant sample contained 64×10^6 f/L. Three samples of clarifier overflow had fiber counts ranging from 27×10^6 f/L–100×10^6 f/L. These values were similar to the amphibole fiber counts in raw lake water at that time. These data and the consistently low fiber counts in the filtered water for the first 3 1/2 years of operation at Duluth indicated that recycling did not affect the water quality when the plant was operated properly.

The data base for Two Harbors and Silver Bay is smaller than that for Duluth because of limitations on funding for asbestos analysis and because the other plants have not operated as long. The results, shown in Table 3, indicate that both of the plants do remove a large percentage of the amphibole fibers, although perhaps not as much as the Duluth plant. Substantial reductions in fiber count are consistently attained.

Filtered water turbidity at Two Harbors generally has ranged from 0.10 ntu–0.20 ntu, and fiber counts have typically been from 0.1×10^6 f/L–2×10^6 f/L. These values were somewhat higher than the values for Duluth and Silver Bay. Turbidity was measured with a different brand of instrument, and the turbidities may not have been directly compa-

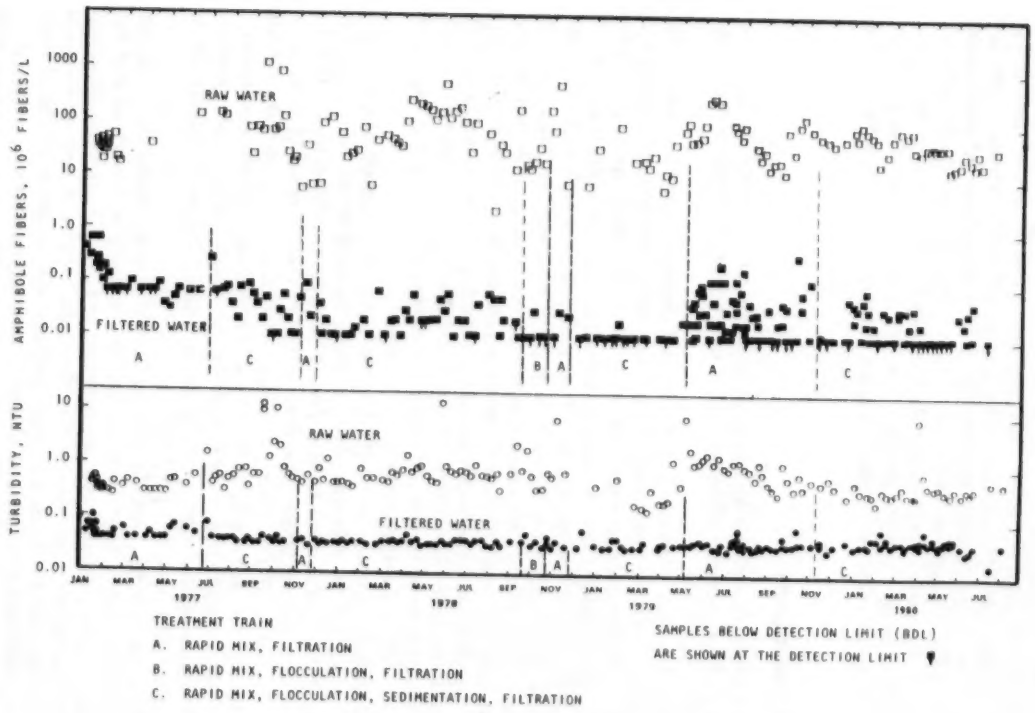

FIG. 4.—Raw and Filtered Water Turbidity and Asbestos Monitoring Data at Duluth

TABLE 3.—Two Harbors and Silver Bay Data

Date (1)	Lab (2)	Raw Water: Turbidity, in nephelometric turbidity units (3)	Raw Water: Fibers, in 10^6 fibers per liter (4)	Filtered Water: Turbidity, in nephelometric turbidity units (5)	Filtered Water: Fibers, in 10^6 fibers per liter (6)	Percent Reduced: Turbidity (7)	Percent Reduced: Fibers (8)
(*a*) Two Harbors Amphibole Data							
4/28/78	EPD	0.6	141	—	—	—	—
5/15/78	MDH	1.2	44	0.14[a]	0.43	88	99.0
6/22/78	MDH	1.0	111	0.16[a]	0.80	84	99.3
6/27/78	EPD	0.78	200	—	—	—	—
7/3/78	EPD	1.3	177	—	—	—	—
7/18/78	EPD	1.5	84	0.10[a]	1.6	93	98.1
7/27/78	MDH	0.8	19	0.15[a]	0.56	81	97.1
8/1/78	EPD	1.0	53	0.20[a]	2.3	80	95.7
9/1/78	EPD	0.66	356	0.10[a]	0.45	85	99.9
9/7/78	MDH	1.0	22	0.15[a]	<0.07	85	>99.7
10/6/78	EPD	1.2	61	0.14[a]	1.9	88	96.9
1/9/79	MDH	—	—	0.13[a]	0.37	—	—
6/28/79	MDH	0.96	65	0.14[a]	0.28	85	99.5
10/16/79	MDH	—	—	0.14[a]	0.097 NSS	—	—
11/10/79	MDH	0.50	—	0.14[a]	0.12 NSS	72	—
7/1/80	MDH	0.36	11.3	0.14[a]	0.12 NSS	61	99
1/6/81	MDH	0.30	2.9	0.06[b]	<0.04	80	>98
5/13/81	MDH	0.30	1.25	0.03[b]	0.14 NSS	90	89
5/13/81	MDH	0.30	—	0.03[b]	<0.034 BDL	90	>97
(*b*) Silver Bay Amphibole Data							
6/22/78	MDH	0.41	25.3	0.05	0.18	88	99.29
7/27/78	MDH	0.41	8.4	0.05	<0.13	88	>98.4
9/5/78	MDH	0.32	1.8	0.07	<0.13	78	>92.8
1/9/79	MDH	—	—	0.05	0.18	—	—
6/28/79	MDH	0.28	14.3	0.04	0.33	79	97.7
10/17/79	MDH	—	—	0.03	0.052 NSS	—	—
12/24/79	MDH	0.27	—	0.04	0.034 NSS	85	—
7/1/80	MDH	0.28	5.3	0.06	0.11 NSS	78	98
1/13/81	MDH	0.18	1.24	0.02[d]	0.02	89	>98
5/13/81	MDH	0.22	0.32	0.02[d]	0.070 NSS	91	78
5/13/81	MDH	0.22	—	0.02[d]	<0.074 BDL	—	>77

[a]May not compare with Duluth and Silver Bay.

[b]Two Harbors replaced Fisher turbidimeter with Hach turbidimeter (mention of commercial products does not imply endorsement by EPA).

[c]Silver Bay purchased a Hach "digital readout" turbidimeter (mention of commercial products does not imply endorsement by EPA).

Note: EPD = EPA-Duluth; MDH = Minnesota State Health Department; NSS = not statistically significant.

rable. The circulation pattern in Lake Superior causes raw water fiber counts at Silver Bay to be considerably lower than counts at Two Harbors and Duluth. The limited amount of data available indicate the Silver Bay plant was effective in removing amphibole fibers from the raw water.

Cascade Mountains.—The Seattle pilot plant results were reviewed by Logsdon, et al. (10). The plant consistently produced water at or below 0.10 ntu. Filtered water above 0.10 ntu generally resulted from inadequate alum dose, deviation from the optimum pH range for alum coagulation (6.1–6.7), or breakthrough at the end of the run (5). The Tolt Reservoir water was similar to Lake Superior in clarity, generally 1.0 ntu or lower. When filtered water turbidity did not exceed 0.10 ntu, asbestos fiber counts were typically reduced by a factor of 100. Granular media filtration thus was shown to be quite effective in treating Cascade Mountain water for asbestos fiber removal. Operating data from the Everett plant are not available yet.

Review

Water Quality Goal for Design.—An engineer designing a water filtration plant for asbestos fiber removal should consider design goals that are not typical. For instance, the 1 ntu maximum contaminant level for turbidity may not be an appropriate water quality goal, if asbestos fiber removal is to be accomplished by filtration (5,6,8). A goal of 0.10 ntu is appropriate for clear surface water such as Lake Superior and reservoirs in the Cascade Mountains (10) because fiber removal is enhanced when the filtration process is removing the largest amount of turbidity-causing particulates.

Plant Design to Produce Low Turbidity Water.—Both the processes that condition raw water for filtration and the filtration process itself play an important role in the removal of asbestos fibers. In 1965 Conley (3) suggested the process of water clarification should be viewed as a whole. Research on asbestos fiber removal confirms the validity of Conley's idea. For a filtration plant to consistently be effective in removing asbestos fibers, each of the unit processes in the clarification process must be operated effectively. One inadequate step in the treatment train can result in higher filtered water turbidity and fiber counts.

The first step in clarification, rapid mixing, was studied in pilot plant research at Duluth, Seattle, and Everett. Two-stage or three-stage backmixing was used in the Lake Superior plants. In-line static mixing was favored in the Seattle pilot plant study and was originally proposed for Everett. However, because of the limited head available, the final design for Everett called for rapid mixing basins. Mixing times vary, but a thorough mixing of chemicals is the goal of the various designs.

Flocculation, which follows chemical addition and rapid mix, is sometimes omitted at direct filtration plants. At the three plants on Lake Superior, however, multistage flocculation has been used. The Everett plant included multistage, tapered flocculation.

Experience related to flocculation has been varied. During the first six months of operation at Duluth, no flocculation was employed, and the plant appeared to function well. On the other hand, the extensive Se-

attle pilot plant work (5) indicated that including flocculation in the treatment train resulted in a longer number of operating hours during which filtered water turbidity was 0.10 ntu or lower. Data from a mixed media package plant with a 0.37 m^2 filter and from a mixed media filter column (11 cm diameter) both showed a positive benefit for flocculation (Table 4). The Everett pilot plant studies also indicated that attaining low turbidity filtered water was difficult when in-line filtration was used (15). This may have been the result of insufficient time for floc growth. Because the need for flocculation may vary at different locations, this process should be studied in pilot plant investigations so the design engineer can determine if the extra costs for flocculation will result in improved plant performance.

A number of factors related to filter design have been observed or evaluated with respect to fiber removal. These include the type of filter media, rate of filtration, type of rate control, and depth of water over the media.

When the Duluth filtration plant was built, dual media was placed in one filter at the Lakewood plant and mixed media was used in the other three. The performance of the two media types was similar during constant rate operating conditions. When filtered water quality deteriorated as a result of a filtration rate change, the quality of the mixed media filter effluent equalled or exceeded that of the dual media filter (8). At Duluth, the filters all received the same water for filtration, and alum and polymer doses are those that produce the desired filtered turbidity from the dual media filter.

TABLE 4.—Effect of Flocculation (Seattle Pilot Plant)

Run number for 0.37 square meter (4 square foot) mixed media package plant filter (1)	Filtration rate, in meters per hour (gallons per minute per square foot) (2)	Hours filtered[a] water turbidity, in ≤ 0.10 ntu (3)	Run number for 11 centimeters diameter mixed media filter (4)	Filtration[a] rate (average) in meters per hour (gallons per minute per square foot) (5)	Hours filtered water turbidity, in ≤ 0.10 ntu (6)
(*a*) Runs with Rapid Mix-Flocculation[b]-Filtration 1/28/78 to 1/29/78 and 2/12/78 to 2/16/78					
127	9.8 (4.0)	10	127M	16.6 (6.8)	7
128	9.8 (4.0)	12	128M	15.9 (6.5)	8
134	9.8 (4.0)	12	134M	9.8 (4.0)	20
135	9.8 (4.0)	13	135M	9.8 (4.0)	19
136	9.8 (4.0)	15	136M	12.2 (5.0)	13
137	9.8 (4.0)	16	137M	13.7 (5.6)	9
(*b*) Runs with Rapid Mix-Filtration 1/30/78 to 2/7/8					
129	9.8 (4.0)	None	129M	14.9 (6.1)	None
130	9.8 (4.0)	8	130M	14.6 (6.0)	None
131	9.8 (4.0)	6	131M	9.8 (4.0)	7
132	9.8 (4.0)	8	132M	12.2 (5.0)	4
133	9.8 (4.0)	5	133M	14.6 (6.0)	None

[a]Data when head loss exceeded 2.4 m (8 ft) excluded.
[b]Flocculation GT approximately 41,000 (70 sec^{-1} G for 9.7 min).

Dual and mixed media filters were compared for both asbestos fiber removal and water production efficiency in Seattle (5). Two runs with three parallel filter columns were carried out, and 45 water samples were analyzed for asbestos. Under normal conditions of operation, all of the different medias tested were effective for asbestos fiber removal.

During the 1974 pilot plant research in Duluth, only a limited number of runs with rates above 4 gpm/sf were sampled for asbestos fibers. Filtration at 5 gpm/sf was expected to be effective for amphibole fiber removal (4). In the Seattle research, rates as high as 10 gpm/sf were found to be effective for asbestos fiber removal.

At Seattle, filters were operated in both declining rate mode and constant rate mode. Both were effective for asbestos fiber removal (5). One possible advantage of variable declining rate filtration is that abrupt rate changes are avoided. As noted previously, research at Duluth showed that fiber counts could increase during abrupt rate increases, particularly when a filter was operating at a high head loss.

Because air binding problems were encountered in the granular media pilot plants at Duluth in 1974, the filtration plant was designed so that 7 ft (2.1 m) of water normally will be over the top of the media during filtration. This has prevented repetition of the air binding problems that occurred in the pilot study.

Maintaining close control of water quality at the treatment plant is important. Frequent or continuous monitoring of raw and treated water is recommended. Seattle pilot plant data and plant operating experiences at Duluth showed the existence of a narrow range of pH (6.1–6.7 at Seattle and 6.9–7.35 at Duluth) that would result in successful treatment, so pH monitoring should be considered. The most readily used quality goal for filtered water is turbidity, and this should be measured continuously. Effluent from each filter should be monitored so the operator can control the filters and backwash each at the proper time.

Other Water Quality Considerations.—Water, especially from a surface source, is seldom treated for only a single purpose. Water delivered to consumers should be clear, colorless, and free of tastes and odors. It should not contain pathogens or harmful amounts of chemicals. The water should not damage distribution system pipes or consumers' plumbing. When filtration plants are designed for asbestos removal, all of the preceding factors should be considered.

Engineers should be particularly careful so that they do not create one problem while solving another. Adjusting the pH of water may lead to problems because pH influences asbestos removal, disinfection, trihalomethane formation, and corrosion. The proper pH for one purpose may be wrong for another. This sort of problem is likely to vary from place to place and needs to be dealt with at each location.

Peterson described two examples of this previously (13). Recycling of lagoon decant water containing sludge residue, in one instance, could upset the treatment plant, so piping was changed to divert lagoon decant water to the wash water treatment system before sending it to the filter plant. Another problem may have been related to coagulation with alum. Use of alum depresses pH and alkalinity, which may have been the cause of rusty water complaints soon after the treatment plant started operating at Duluth. The problem, related to galvanized iron or steel

plumbing, was eliminated by use of sodium hexametaphosphate and zinc orthophosphate.

Design engineers should be aware of the various water quality problems that may occur during plant operation. If the design provides for a wide choice of process variations and flexibility in addition of treatment chemicals, the operator will be better equipped to deal with unforeseen difficulties as they arise.

Mechanism of Fiber Removal.—The granular media filtration process can effect substantial reductions in the concentration of asbestos fibers in drinking water, particularly when filtered water turbidity is 0.10 ntu or lower. The mechanisms by which the fibers are removed are uncertain. Because of the very small size of the fibers (about 1 μm in length and about 0.2 μm or 0.3 μm in width for amphibole, less than 0.1 μm in width for chrysotile), removal by straining in granular media would be highly unlikely. Removal by sedimentation or interception in the filter bed, followed by attachment, is much more likely. For the fibers to remain in the filter during the run, they should be destabilized in order to adhere to the granular media, or to adhere to fibers previously removed from the water and adhering to the media.

The influence of the surface charge of asbestos fibers on their removal was analyzed by Logsdon and Symons (9). In the pH range (6–8) at which coagulation was practiced at Duluth and Seattle, amphibole fibers were presumed to possess a negative surface charge whereas chrysotile fibers were thought to have a positive surface charge. Measurements of electrophoretic mobility or zeta potential would be made on suspensions of fibers much more concentrated than those found in natural waters. Whether these fibers possess the same surface charges in natural waters is unknown.

On the assumption the surface charge of individual fibrils was similar to the measurable charge of the fiber bundles, pilot plant experiments at Duluth (9) were conducted with nonionic, cationic, and anionic polymers. In the Seattle pilot plant study, a limited amount of work was done with anionic polymers for chrysotile removal, but this was not pursued in depth because other techniques proved adequate for chrysotile removal (5). In run 53, the use of cationic polymer as the only coagulant at a dose of 3 mg/L resulted in a 92.5% decrease in chrysotile concentration. In three other runs in which fiber counts were obtained, alum was partially replaced with cationic polymer (3 mg/L–5 mg/L alum along with 2 mg/L polymer). In these runs chrysotile removal ranged from 86%–99% when filtered water turbidity was 0.10 ntu or lower.

On the basis of information about the surface charge of chrysotile asbestos, anionic polymers rather than cationic polymers should be effective for chrysotile removal in granular filters. A clue to the effectiveness of cationic polymer alone or in combination with alum may be elucidated from transmission electron microscope photographs of chrysotile fibers in raw water samples. The fibers are usually observed in proximity to other particles (5). If chrysotile fibers attach to or become associated with clay particles, bacteria, or other small negatively charged particles, then conditioning and filtering water for removal of the latter sorts of particles would result in the concurrent removal of chrysotile.

The concept of concurrent removal of chrysotile and negatively charged

particles has not been evaluated in laboratory studies. Such an evaluation, however, does not need to be made before water filtration plants can be designed and operated. On the basis of successful pilot plant tests (5,15), engineers have shown that providing for use of anionic polymer is not necessary in order to filter out chrysotile asbestos.

Practical Application

At the present state of knowledge about filtration, a pilot plant study usually should be carried out before a water filtration plant is designed for asbestos fiber removal to help designers evaluate optimum filtration rates, coagulation dose and type, the need for flocculation, and media type, just to cite a few examples. The treatment objective should be to produce water with a turbidity of 0.10 ntu or lower. The plant should be designed to provide the operator with as much operating flexibility as possible.

Water treatment plants that filter water for the purpose of removing asbestos fibers should continuously monitor the effluent turbidity from each filter, in order to detect changes in filtered water quality as soon as possible. Plants should be designed with this monitoring need in mind. The designer should also provide for convenient monitoring of pH and means of pH control (both acid and base) so that the optimum value of pH can be maintained at all times.

Deep granular media filter boxes (about seven feet of water over media) may be necessary to provide enough depth of water above the media to prevent air binding problems. An alternative is to carry the effluent flow over a weir above the media and allow the water level to rise as the head loss develops. This is the procedure used in influent flow splitting and declining rate filtration plants.

Conclusions

1. Asbestos fiber removal by granular media filtration has exceeded 99.99%.
2. Filtration plants should be designed to produce filtered water having a turbidity of 0.10 ntu or lower.
3. Proper conditioning of raw water is essential for effective fiber removal. Adequate coagulant must be used to completely destabilize all particles. Filter aids may be needed to prevent turbidity breakthrough.
4. Although concentrated suspensions of chrysotile fiber bundles possess a positive zeta potential at natural water pH values, very dilute chrysotile suspensions in raw water have been treated by coagulation with alum or cationic polymer or both. Use of anionic polymers for chrysotile removal is not necessary.
5. The need for flocculation should be determined during pilot plant studies.
6. Granular media filters can remove asbestos fibers at filtration rates of 2 gpm/sf–10 gpm/sf. Depending on local circumstances, both backmix and in-line or static mix techniques can be effective.
7. Designing to prevent occurrence of negative pressure (less than atmospheric) in the filter media prevents air binding problems.

APPENDIX.—REFERENCES

1. Baumann, E. R., "Diatomite Filters for Asbestiform Fiber Removal from Water," Paper 10-2c, *Proceedings*, American Water Works Association Annual Conference, Minneapolis, Minn., 1975, pp. 2–5.
2. Chatfield, E. J., and Dillon, M. J., "A National Survey for Asbestos Fibers in Canadian Drinking Water Supplies," *79-EHD-34*, Department of National Health and Welfare, Ottawa, Ontario, Canada, 1979.
3. Conley, W. R., Jr., "Integration of the Clarification Process," *Journal American Water Works Association*, Vol. 57, No. 10, Oct., 1965, p. 1333.
4. "Direct Filtration of Lake Superior Water for Asbestiform Fiber Removal: Project Report and Appendices A through I," *EPA-670/2-75-051a–EPA-670/2-75-050g*, Black & Veatch Consulting Engineers, United States Environmental Protection Agency, Cincinnati, Ohio, 1975.
5. Kirmeyer, G. J., "Seattle Tolt Water Supply Mixed Asbestiform Removal Study," *EPA-600/2-79-125*, *EPA-600/2-79-126*, and *EPA-600/2-79-153*, United States Environmental Protection Agency, Cincinnati, Ohio, 1979.
6. Kirmeyer, G. J., Logsdon, G. S., Courchene, J. E., and Jones, R. R., "Removal of Naturally Occurring Asbestos Fibers from Seattle's Cascade Mountain Water Source," *Proceedings of the 1979 Annual Conference*, American Water Works Association, Part 2, 1979, pp. 903–927.
7. "Lake Chaplain Water Treatment Plant, Concept Report and Initial Layout," Collins, Ryder & Watkins, Consulting Engineers, and Gray & Osborne, Consulting Engineers, Seattle, Wash., Feb., 1980.
8. Logsdon, G. S., "Water Filtration for Asbestos Fiber Removal," *EPA-600/2-79-206*, United States Environmental Protection Agency, Cincinnati, Ohio, 1979.
9. Logsdon, G. S., and Symons, J. M., "Removal of Asbestiform Fibers by Water Filtration," *Journal American Water Works Association*, Vol. 69, No. 9, Sept., 1977, pp. 499–506.
10. Logsdon, G. S., Symons, J. M., and Sorg, T. J., "Monitoring Water Filters for Asbestos Removal," *Journal of the Environmental Engineering Division*, ASCE, Vol. 107, No. EE6, Proc. Paper 16748, Dec., 1981, pp. 1297–1315.
11. Millette, J. R., Clark, P. F., and Pansing, M. F., "Exposure to Asbestos from Drinking Water in the United States," *EPA-600/1-79-028*, United States Environmental Protection Agency, Cincinnati, Ohio, 1979.
12. Patton, J. L., "Unusual Water Treatment Plant Licks Asbestos Fiber Problem," *Water and Wastes Engineering*, Vol. 14, No. 11, Nov., 1977, pp. 41–44, 50.
13. Peterson, D. L., Schleppenbach, F. X., and Zaudtke, T. M., "Direct Filtration of Lake Superior Water," *Proceedings of the 1979 Annual Conference*, American Water Works Association, Part 1, 1979, pp. 237–256.
14. Robinson, J. H., Schmidt, O. J., Stukenberg, J. R., Jacob, K. M., and Bollier, G. H., "Direct Filtration of Lake Superior Water for Asbestiform Solids Removal," *Journal American Water Works Association*, Vol. 68, No. 10, Oct., 1976, pp. 531–539.
15. Watkins, J., Jr., Ryder, R. A., and Persich, W. A., "Investigation of Turbidity, Asbestos Fibers, and Particle Counting Techniques as Indices of Water Treatability of a Cascade Mountain Water Source," Paper 33-3, *Proceedings of the 1978 Annual Conference*, American Water Works Association, Part, 2, 1979, pp. 5–16.

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